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# Treating Anisekonion with Stock Base Curve Manipulation in Asymptomatic Adults

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# Treating Aniseikonia with Stock Base Curve Manipulation in Asymptomatic Adults

## Abstract

**Purpose:** The purpose of this study was to predict the base curve of the spectacle correction of patients in order to minimize their aniseikonia. We hypothesized that in order to correct the patient's aniseikonia, we can manipulate the base curve of the subject's prescription to change the magnification, without ultimately altering the prescription.

**Methods:** Ten female adults with spherical equivalent of  $\geq 1$  D anisometropia, and visual acuity of 20/25 or greater corrected vision, were studied. The participants were evaluated for anisometropia while wearing their habitual spectacles (i.e. non-size lens) and reassessed 4 weeks later ( $\pm 2$  weeks). A-scan ultrasound biometry and keratometry measurement were determined at first visit. Ocular history, visual acuity, refraction, stereopsis at near, and aniseikonia subjective symptoms was evaluated at each visit. Aniseikonia amount was measured by the Brecher test and Aniseikonia Inspector Software test for both spectacles and with contact lenses. Size lens spectacles were prescribed according to the findings of the first visit with new frames using two base curves: 2 D (the flattest base curve) and 6 D (steepest base curve) for the subjects to be used full time.

**Results:** Seven subjects were classified as axial anisometropes and three had the mixed type. Anisometropia spherical equivalent of  $\geq 1$  D caused aniseikonia of at least 1 %. A good model of predication about the relationship between the axial length and anisometropic SE difference between the two eyes was shown. Visual acuity improved ( $P < 0.05$ ) one line with size lens spectacles. Stereopsis was not affected ( $P > 0.05$ ) for all subjects except one, who showed improvement. Aniseikonia decreased with size lens spectacles by 57.5 % from the first visit ( $P < 0.05$ ). Aniseikonia improved more when the subjective phoria was compensated by loose prism, as needed, to 95 percent ( $P < 0.05$ ), regardless of the subject's anisometropia type. There were no statistically significant ( $P > 0.05$ ), differences of the symptoms between habitual spectacles, contact lenses and size lens spectacles, but there was a clinically significant change of headache, asthenopia, photophobia and reading difficulty with size lens spectacles compared to habitual spectacles and contact lenses. The mean average of the two aniseikonia tests was 0.7845 percent per one diopter of anisometropia spherical equivalent.

**Conclusions:** Manipulation of the size lens spectacle base curve helps to correct aniseikonia. Prism is one of the option to treat aniseikonia but further study is necessary to show the relation between aniseikonia and prism.

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**TREATING ANISEKONIA WITH STOCK BASE CURVE MANIPULATION IN  
ASYMPTOMATIC ADULTS**

By

**NORAH IBRAHIM AL-HABDAN**

A THESIS

Submitted to the Graduate Faculty of Pacific University Vision Science Graduate Program

in partial fulfillment of the requirements for the degree of

Master of Science

In

Vision Science

PACIFIC UNIVERSITY

COLLEGE OF OPTOMETRY

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PACIFIC UNIVERSITY COLLEGE OF OPTOMETRY  
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This thesis of **NORAH IBRAHIM AL-HABDAN**, titled “Treating Aniseikonia with Stock Base Curve Manipulation in Asymptomatic Adults”, is approved for acceptance in partial fulfillment of the requirements of the degree of Master of Science.

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Master of Science in Vision Science

College of Optometry

Pacific University Oregon, 2016

**NORAH IBRAHIM AL-HABDAN**

## ABSTRACT

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**Conclusions:** Manipulation of the size lens spectacle base curve helps to correct aniseikonia. Prism is one of the option to treat aniseikonia but further study is necessary to show the relation between aniseikonia and prism.

**Key words:** Anisometropia, Axial Length, Knapp's Law, Aniseikonia, Size Lens, Stereopsis



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## INTRODUCTION

Anisometropia is a visual condition in which a patient's left and right prescriptions are unequal.<sup>1,2,3</sup> Despite this straightforward definition for this uncommon condition, there is still a lack of agreement about its origin. There are some misunderstandings about the degree to which patients' eyes need be anisometric to qualify for clinical significance. According to Woodhouse, a difference in refractive error of more than 1.00 diopter in spherical equivalent is considered significant.<sup>4</sup> Some studies provide a more detailed definition for anisometropia. Oaastadimoghaddam et al. defines anisometropia as the interocular difference in spherical equivalent refractive error on the non-cycloplegic refraction.<sup>5</sup> The implications of Oaastadimoghaddam's et al. definition works to provide a classification scheme for anisometropia.<sup>5</sup> This is important because there are different ways in which a patient's eyes can have unequal refractive power.

For instance, anisoastigmatism is a condition where a difference ( $\geq 1.00$  D) in interocular cylinder refraction exists. There are further classifications for anisometric eyes that are both myopic and hyperopic. If a difference in spherical equivalent difference is 1.00 D or more, and both eyes are myopic, the patient has anisomyopia; whereas, a spherical equivalent difference is 1.00 D with two hyperopic eyes the patient has anisohyperopia. It is important to discuss the condition of anisometropia and the nuances of the separate, yet similar conditions of anisomyopia, anisohyperopia, anisoastigmatism in order to understand their relationship with other conditions such as amblyopia and strabismus.<sup>5</sup>

### *Anisometropia and Visual Development*

Anisometropia is considered to be one of the leading causes of amblyopia.<sup>6</sup> Though the connection between anisometropia and amblyopia is understandable, the mechanism of anisometropic amblyopia is poorly understood. Von Noorden claims that one explanation might be there is active suppression of the fovea of the defocused eye to eliminate sensory interference caused by the conflicting superimposition of a focused and defocused image. In order to get a better understanding of these conditions independently, it is worthwhile to review a few studies on the presence of anisometropia in children.<sup>7</sup>

One study put forth by Birch et al. found that 25% of the children with anisometropia at age 1.5 years were still anisometropic at age four. This study suggests that the individuals have the ability to decrease the differences in refractive power between their eyes, especially when anisometropia is detected at a young age.<sup>8</sup> Another study from Robert and Adams supports this observation.<sup>9</sup> Robert and Adams claims that anisometropia in infants is often transitory, and holds little risk of causing amblyopia after maturity. That said, infants with high anisometropia ( $\geq 3D$ ) at age 1 are likely to remain anisometropic at age 4 and have a significant risk of becoming amblyopic in maturity. In the severity of amblyopia and the difference in refraction display a correlation with both myopes and hypermetropes; that said, there is one study the shows a greater correlation between anisometropia and refraction in myopes.<sup>5</sup> It is being expected that a child with 1D or more of anisohyperopia would be more likely to become amblyopic than a child with an equivalent difference in two myopic eyes.<sup>5</sup> This expectation supports the assertion made by Von Noorden that the mechanism of anisometropic amblyopia is

actively inhibiting the fovea in order to reduce sensory interference of the superimposition of one focused and one unfocused image.<sup>9</sup>

According to Borchert et al., the amount of anisometropia varies in different studies; anisometropia may be dependent on age inclusion criteria, history of ocular pathology, and etiology of various ocular conditions.<sup>10</sup> There is little evidence to show that ethnic or racial difference play a role in the development of anisometropia, because these factors have not been studied directly, nor have environmental factors been shown to play a role in the development of anisometropia.<sup>10</sup>

### *Anisometropia and Emmetropization*

Though it is possible for anisometropia to lessen as a child matures, Sjostrand reports that high anisometropia ( $\geq 3.00$  D) at 1 year of age will likely persist into maturity in his study.<sup>6</sup> A study in 2006 by Eva Larson and Gred Holmstrom found similar results. In their study Larson and Holmstrom found that children with high anisometropia ( $\geq 2.00$  D) remained anisometric during their study. They confirmed through multiple regression analysis that anisometropia of 2.00 D or more at 2.5 years old was the only risk factor for anisometropia of 1.00 D or more at 10 years old.<sup>11</sup> Larson and Holmstrom also discovered that children with cryotreated severe ROP had the high occurrence of anisometropia or high anisometropia ( $\geq 2.00$  D) in all of their three retinoscopic examination results. From this observation of children maturing with anisometropia (i.e. the prevalence of anisometropia persisted), Larson and Holmstrom concluded that it was likely that the process of emmetropization had already been disturbed in the early stages of life.<sup>11</sup>

The impact that anisometropia has on emmetropization is difficult to measure, but the effect is understandable. According to an article from Barrett et al., the prevalence of

anisometropia is greater in groups that are highly ametropic, and this suggests that emmetropization failures underlying anisometropia and ametropia might be related.<sup>12</sup> The connection between the amount of ametropia and the prevalence and degree of anisometropia implies that an increase in the failure of emmetropization is linked with an increasing failure of coordinated eye growth across both eyes.<sup>12</sup> It is likely then, understanding the origins of anisometropia could provide greater insight into our understanding of the origins of ametropia.

In addition to research that shows the prevalence of anisometropia in children through adolescence, there are studies that show there is stable prevalence of anisometropia between the ages of 20 and 40 years: around 11-13% of subjects, in a large scale study carried out by Qin et al, exhibited anisometropia of  $\geq 1.00\text{D}$  in spherical equivalent.<sup>13</sup> Another sample from 1997 of approximately 4500 US adults 40 and older found that anisometropia (i.e.  $\geq 1.00\text{D}$  difference in spherical equivalent refraction) increased with age in the population from about approximately 4.8% when subjects were 40-49 years old, to about 14.8% when subjects were aged 80 years and older. This increase of anisometropia in aging individuals is evident in many cross-sectional, population based studies cited in “The relationship between anisometropia and amblyopia.”<sup>12</sup>

So according to many researchers the prevalence of anisometropia can be developed throughout youth, and manifest in severe forms in later ages; however, there are other studies that show that some cases of anisometropia are linked to congenital and other etiologic mechanisms of anisometropia.<sup>14</sup> Tomac claims that the etiology of anisometropia differs at different ages. Tomac goes to argue that main causes of anisometropia in childhood are congenital, such as cataracts, or asymmetry of the biometric components of the eye, like the axial length. For older patients with anisometropia, it is more likely that the condition was acquired. Trauma, glaucoma, and cataract, as well as some surgeries have the potential to create



anisometropia in older individuals.<sup>14</sup> Most reports on the prevalence of anisometropia shows a wide range. For instance, in Myanmar the prevalence of anisometropia is 35.5%, versus 1.6% in Australia.<sup>5,15</sup> This does not help to clear up the cultural or ethnical implications of anisometropia, but offers an insight into the impact it has on different groups of people nonetheless.

Researchers, however, say it remains unclear how geographic differences affects myopia.

Morgan thinks sunlight may stimulate the release of dopamine from the retina and inhibit the elongation of the eye that results in myopia.<sup>47</sup> The mechanics of how sunlight protects their eyes are not clearly understood. Another theory speculates that blue light from the sun protects from the condition.<sup>47</sup> Researchers say kids and teens need to get enough sunlight during the critical years of their development while their eyeballs are still growing.<sup>47</sup> There is also the possibility that larger numbers of unilateral pseudophakes or aphakes in equatorial countries skew these demographics. The epidemiology of anisometropia has been discussed in many reports, but reports are limited that investigate the wide age ranges of the prevalence of anisometropia.

Though it is important to realize that the prevalence of anisometropia among aging individuals is increasing, it is more important to emphasize the prevalence of anisometropia in youths because of the association that it has with amblyopia as well as the potential anisometropia has to get worse and affect the patient for decades to come.

### *Treatment of Anisometropia*

Treatment for anisometropia is possible; however, the outcome for patients with higher degrees of anisometropia is worse. Furthermore, there has been a correlation in the degree of anisometropia and the depth of amblyopia. High degrees of anisometropia cause a difference in

the image size between the two eyes (this can lead to a condition known as aniseikonia, the topic of the current study). Many studies suggest that a anisometropia level of more than 3.50 D creates a barrier to visual fusion: these patients may be left undercorrected with a small chance of improving their amblyopia.<sup>16,17</sup>

### *Anisometropia and Aniseikonia*

As mentioned earlier, anisometropia is a visual condition in which a patient's left and right prescriptions are unequal, this can be a result of a difference in refractive power, or axial length. When a difference in axial length is the cause of a patient's anisometropia (i.e. axial anisometropia), the result can leave the optical power unaffected. Patients with axial anisometropia often have a refractive power of 2.00 D or greater.<sup>3,18</sup> Furthermore, if the anisometropia causes a difference in retinal image sizes, then the condition might be classified as aniseikonia: it is possible for a patient to have differing retinal image sizes, and not be classified as aniseikonic.

It is important to emphasize the difference between aniseikonia, and a basic difference in retinal image size. For instance, a patient could have a difference in retinal image size, and experience no difference in cortical image size. Aniseikonia relies on the fact that the patient is experiencing a difference in the perceived cortical image sizes of image due to the difference in retinal image size. In addition, it possible for aniseikonia, and patients with differing retinal image sizes to occur in either corrected and uncorrected eyes.

### *Aniseikonia and Knapp's Law*

Correction of aniseikonia can be achieved through prescription lenses. Knapp's Law attempts to determine the most appropriate type of prescription to diminish aniseikonia. According to Knapp's Law, it is possible to place spectacle correction at the anterior focal plane in order to equalize the retinal image sizes, but only in certain types of aniseikonia. Knapp's law states that if a correcting lens is placed before an axial ametropic eye so that its second principal point coincides with the primary focal point of the eye (~17mm), the resulting retinal image will be the same as that of an emmetropic eye.<sup>19</sup> This correction method would not be sufficient for patients with refractive anisometropia; anisometropia relies on correction at the corneal plane of the spectacle magnification. Since Knapp's time, contact lenses have made this possible for refractive anisometropes.

Knapp's Law is mathematically correct; however, it can fail in clinical practice. Part of the law states that "the refractive power of the eye must be equal to that of the standard emmetropic eye," this tenet of the law suggests that differing retinal image sizes resulting from refractive ametropia cannot be rectified with spectacle lenses. However, Knapp did not consider cortical magnification as a major factor in aniseikonia.<sup>20</sup> For example, in amblyopia, the sound eye has often less hyperopia but greater cortical magnification. Because of this shortcoming implied by Knapp's Law, contact lens correction has been offered to patients with both axial anisometropia and aniseikonia. Kowal et al. outline the method in which they prescribe contact lenses to spectacle wearing, myopic anisometropes in order to gauge their aniseikonic responses.<sup>3,21</sup>

### *Symptomatic Aniseikonia*

Aniseikonia from anisometropia can often be difficult to identify, because patients that have these conditions, as well as corrective spectacles, often exhibit an adaptation to the different right and left cortical image sizes. This adaptation is rare for patients with more than 5% aniseikonia, and the symptoms may even be suffered by patients with 3% or less.<sup>3,22</sup> Furthermore, Crone and Leuridan mean tolerances of 7%. This value is the average residual aniseikonia in examples of a patients that have a unilateral aphakia corrected with contact lenses.<sup>3,23</sup> That is primarily the reason that intraocular lens implants have the greatest potential to reduce the difference of perceived image sizes.

When dispensing anisometropes with spectacles for the first time, it might be necessary to investigate the occurrence of aniseikonia; especially if the patient has good acuities in both eyes. Sometimes, ophthalmic prisms are necessary if the patient's fusion of the two images is hindered by their degree of aniseikonia. It is important to remember that the curvature, thickness (t) and refractive index (n) of a lens will affect the shape factor element (F), given by one of the magnification lens (i.e.  $1 / [1 - (t/n) F]$ ).<sup>3</sup>

Another issue to assess and control is the instance of dynamic aniseikonia. Dynamic aniseikonia is defined as “a heterophobia which varies in magnitude with prismatic effect as the eyes deviate from the optical center of the spectacle lens”.<sup>3,22</sup> Dynamic aniseikonia is a consequence of Prentice's rule applied to anisometropic corrective lenses. Combining spectacles with contact lenses and changing the vertex distance of spectacle frames are also ways to alter the magnification factor of the correcting system.

### *Diagnosing Aniseikonia*

Cases of aniseikonia have been noted for decades, originally defined by Walter Lancaster, who became head of the Dartmouth Eye Institute in 1940.<sup>24</sup> During the 1930s and 1940s, Dartmouth Eye Institute developed instruments to measure the minute differences in image size. The work done by the Dartmouth Institute led to the first treatment for symptoms related to aniseikonia.<sup>25</sup>

Dating to this era, many researchers argued that the most effective way to diagnose aniseikonia is the Space Eikonometer. However, this long discontinued, bulky machine has been eclipsed by other forms of testing that have been developed and used more recently.<sup>26,7</sup> Since the later 20<sup>th</sup> century, clinicians have been using the Maddox-rod based Brecher test, the double Maddox rod-based Miles test, as well as the “New Aniseikonia” (Awaya) plate test, and most recently, the Aniseikonia Inspector Software to determine the degree to which a patient has aniseikonia.<sup>25</sup> Both the Brecher test and the Aniseikonia Inspector software were used in the present study.

### *Causes of Aniseikonia*

Aniseikonia can theoretically be caused by many factors that also cause anisometropia, including differences in ocular size, axial length, refractive error, and retinal or neural distribution of photoreceptor cells and receptive fields, respectively.<sup>28</sup> Retinotopic mapping is a process in which both eyes simultaneously create images from corresponding retinal points. If a difference in eye size, or refractive power exists between the left and right eye, then a difference in the perceived size of the image will occur. Aniseikonia can also result when a longstanding

anisometropia for which the visual cortex is adapted is suddenly eliminated by monocular cataract surgery or monocular refractive surgery. Full monovision correction with contact lenses or surgery can also create aniseikonia.

Aniseikonia can also be associated with oblique astigmatism, and commonly with retinal diseases such as epiretinal membrane and vitreomacular traction.<sup>28,29</sup> There are several conditions and factors that may contribute to aniseikonia, but the focus of this study is to examine the effects of lenses specifically designed to mitigate the instance of aniseikonia, as well as non-aniseikonic lenses ability to address this condition. In order to examine the variables in this study, more information must be provided on the two main types of aniseikonia.

### *Consequences of Aniseikonia*

The way in which patients function with aniseikonia is an important topic of discussion in this study. As stated previously, aniseikonia occurs when the cortex receives an image that is abnormally unequal to the two eyes in size, shape, or luminance. In general, the brain can compensate for some degree of image inequality, including oblique aniseikonia; however, if the image inequality is severe, then stereoacuity will be impaired.<sup>30</sup>

Aniseikonia is not necessarily the cause of amblyopia, but it is often associated with congenital or acquired anisometropia. There have been frequent cases of aniseikonia related high anisometropia, such as unilateral aphakia, in the last few decades. In some cases, the degree of aniseikonia has been reported to be as high as 35%.<sup>30</sup> Considering the availability of contact lenses, and the development of intraocular lenses (IOLs), it is likely that aniseikonia can be avoided altogether.

Despite the widespread practice of refractive surgery, and prevalence of emmetropic pseudophakia, aniseikonia has been more frequently reported in patients after surgeries relating to corneas and cataracts. Haring et al. reports near-vision aniseikonia in up to 12% (mean 2.4%) of patients that were implanted with the first generation of multifocal IOLs. In another study, Kramer et al. found that up 10% aniseikonia (mean 4.1%).<sup>31</sup> Furthermore, a study investigating a population with pseudophakic patients, they report subjective complaints of aniseikonia at 40.2%.<sup>31</sup> Huber and Binkhurst also promote caution about aniseikonia induced by the implantation of anterior chamber IOLs for patients with high degrees of anisometropia.<sup>30,32</sup> Huber and Binkhursts' findings show that aniseikonia is not a marginal problem, and that aniseikonia be considered with every anisometropia patient, especially anisometropia patients seeking lenticular refractive correction.

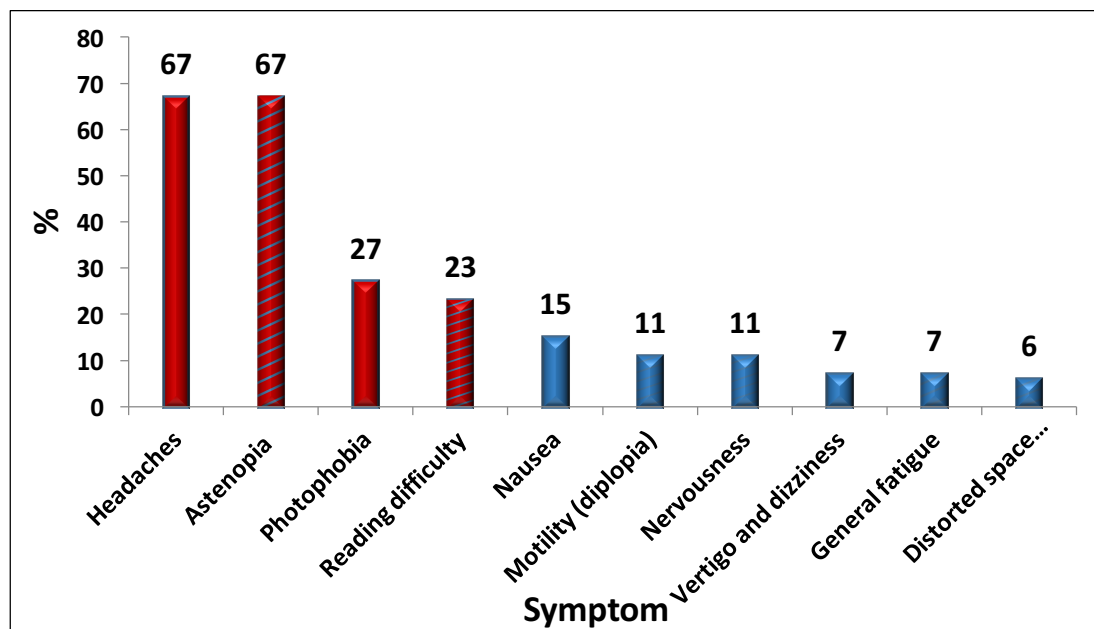
Knapp's law has the potential to provide corrective lenses and spectacles to remedy axial anisometropia without inducing aniseikonia.<sup>33</sup> But as stated previously, this law lacks clinical evidence to support this correction. Away and Von Noorden provide an explanation to the shortcoming of Knapp's Law on the treatment of anisometropia; they argue that pure axial anisometropia is a rare condition, because it is commonly combined with the presences of refractive anisometropia (either corneal or lenticular).<sup>34</sup>

The degree to which a patient has aniseikonia can be determined by many subjective measures, most often these results are observed in patients with unilateral cataracts or on psychophysical studies. Other subjective methods of measurement are the phase-difference haploscope or the Space Eikonometer. With such subjective measurements, it is often difficult to record accurate measurements of aniseikonia in infants, and other young patients.<sup>35</sup>

## *Symptoms of Aniseikonia*

Aniseikonia is always the result of anisometropia—a binocular condition that manifests when patients' traditional corrective lenses cause the eyes to perceive the same image as two different sizes. This size difference emerges in the occipital cortex in the occipital lobe, one of the four major cortices in the brain where the visual processing center resides.<sup>36</sup> Aniseikonia results from the individual eyes to perceive unequal images when focusing.<sup>18</sup>

This difference in the size of ocular images can lead to many effects on binocular vision. First, the binocular stereoscopic interpretation can be altered, if the disparity of the images relative to corresponding point and areas on the two retinas is atypical.<sup>18</sup> Second, the difference in image size can cause problems with fusion; this can be a result of many symptoms discussed later in this study. The amount of studies that report cases of anisometropia (approximately 2.5%) necessitates further research into correction methods for patients with this condition.<sup>24,37</sup>



**Figure 1:** Characteristic symptoms reported by 500 patients referred for aniseikonia examination<sup>38</sup>



This negative corrective effect of anisometropia (or sudden iatrogenic anisometropia caused by cataract and refractive surgery) can lead to several symptoms (Fig. 1) that make vision a struggle for the patient.<sup>38</sup> Though a patient is often diagnosed with both aniseikonia and anisometropia, because they often represent the cause and consequence of the same vision problem, the actual relationship between the two deficiencies has yet to be fully understood. For example, data from the 1940s indicates that diplopia is rarely a symptom.<sup>39</sup>

Aniseikonia can manifest in patients in several different ways: these symptoms can range from being physical to optical to neurological. The physiological symptoms that manifest in patients with aniseikonia include photophobia, amblyopia, as well as excessive tearing. If a patient reports these symptoms, then the probability that the individual suffers from aniseikonia is relatively great, especially, if the patients relies on differing refractive corrections in each eye to obtain clear, single binocular vision.<sup>28</sup>

Relatively few patients with aniseikonia report mobility difficulties due to diplopia. In addition, some patients can experience spatial distortions accompanied and impaired depth perception. The effect that aniseikonia has on the depth perception (stereopsis) significantly impacts the ability of the patient to interpret monocular and binocular clues.<sup>40</sup> Keratometry can offer insight into the causality of the anisometropia and the presence of aniseikonia. For instance, if there is a significant difference in the patient's corneal power and anisometropia is present, then it is likely that the difference in refractive power is the main cause of the anisometropia. Conversely, if the corneal powers are nearly identical then the cause of the anisometropia is likely due to the differing axial lengths of the patients' eyes. According to the

traditional Knapp's Law, axial length differences can be corrected with spectacle lenses ideally located at the anterior focus of the eye to produce equal retinal images sizes.<sup>28</sup>

### *Congenital vs. Acquired Aniseikonia*

It is possible for anisometropia or aniseikonia in infancy or childhood to lead to irreversible impairment in later life; however, it is possible, in adults with unilateral aphakia, to restore binocular function with the use of contact lenses, specific sized lenses, intraocular lenses, or a combination of these methods. In clinical studies, the level of aniseikonia in unilateral aphakia is reported to be approximately 20% when corrected with glasses, 10% when corrected with contact lenses, and only 2.5% with IOL implants.<sup>35,41</sup> That said, the IOL performed well when it came to binocular function.

In a particular study, the binocular system was capable of fusion of up to 3% aniseikonia, yet when aniseikonia reached or surpassed 5%, there was no significant binocular summation for any of the patients. In cases of high aniseikonia (8-10%) the monocular visual evoked response (VER) amplitudes were larger than the binocular VER. This might be attributed to the binocular inhibition due the large difference in the perceived retinal image size.<sup>35</sup> Furthermore, it is likely that binocular function may be capable of visual fusion to compensate for the smaller difference in perceived retinal size; however, when the difference surpasses a certain level, fusion ceases and might instead result in binocular inhibition, resulting in the smaller binocular VER amplitude.

### *Treatment of Aniseikonia*

Since there is likely correlation between anisometropia and aniseikonia, the following guideline should be considered when attempting to correct these various types of anisometropia:

1. Pure axial anisometropia:
  - a. The first method for correction should be spectacles.
  - b. Cataract surgery is a possibility. If this is the case, the goal should be to emmetropize the dominant eye.
  - c. IOLs can also remedy the problem. The power of the IOL (in the surgical eye) should be the difference between the emmetropizing power in the surgical eye, minus the difference between both axial powers.
2. Corneal anisometropia:
  - a. Contact lenses
  - b. Refractive surgery
  - c. Cataract surgery.
3. Lenticular anisometropia:
  - a. The best form of correction would be cataract surgery (in older patients).
  - b. Refractive surgery can be more effective with younger patients.
4. Combined anisometropia:
  - a. The anisometropic components must be considered independently.
  - b. The balance of the induced aniseikonia must be calculated in regards to the surgeries considered as well as retinal causes (e.g. epiretinal membrane).

Traditionally, research has shown that the aniseikonic limit of the human visual system cannot exceed 2% difference between the images sizes of the two eyes; otherwise, fusion becomes too difficult for the binocular system to work properly. Clinically, there is a “rule of thumb” that for every one diopter of corrected anisometropia results in 1% image size difference between the two eyes.<sup>24</sup> In a study looking at the effect of stereopsis on aniseikonia, by using a random-dot stereogram, Oguchi and Mashima observed that between 3% and 5% of aniseikonia patients still experienced binocular summation, and also that stereopsis was present.<sup>24,42</sup>

By modifying the magnification of the current ophthalmic spectacle lens technology it is possible to rectify aniseikonia. Achiron.et.al. apply five factors of aniseikonia correction: base curve, refractive index, center thickness, sagittal depth of contemporary aspheric lenses, and high index lenses, in order to reduce the size differences (<5%) to tolerable vision.<sup>24</sup>

There are two main methods for aniseikonia correction: contact lenses and aniseikonic spectacle lenses; however, the preferred form of treatment is contact lenses. In some cases, patients are unable to use contact lenses; therefore, in this study patients will be prescribed aniseikonic spectacle lenses. The procedures for prescribing the spectacle lenses to patients has traditionally depended on Knapp’s law.

### *Study purpose*

The purpose of the study is to predict the base curve of the spectacle correction of the patients that will minimize their aniseikonia. By manipulating the base curve of the lens power from the subject’s prescription to change the magnification, without ultimately altering the prescription. This will result in the correction of the patient’s aniseikonia.

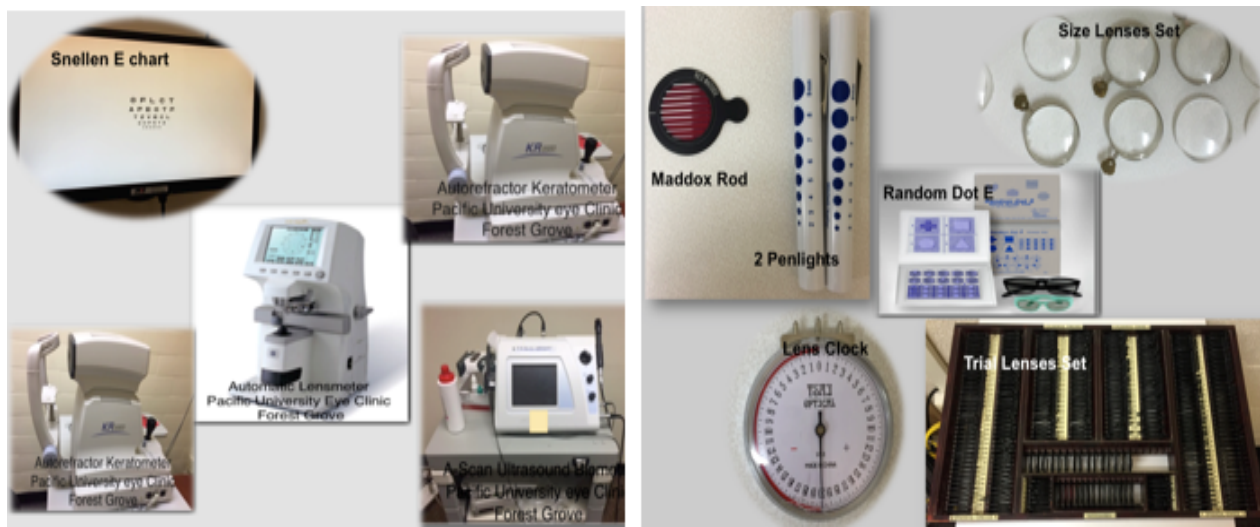
## **MATERIALS and METHODS**

Research participants were recruited from current students, patients, and faculty at Pacific University College of Optometry in Oregon. In this study there were 12 voluntary participants, including the author. Besides the tests performed on the researcher of this study (which were carried out by the researcher's thesis advisor) all test were performed by the researcher at two locations in Oregon: the Pacific University Eye Clinic in Forest Grove, as well as the Pacific Eye Clinic, Portland. The mean age of the 12 participants was 29.60 (SD of 7.69), all participants were female, and had an ocular history of anisometropia with a spherical equivalent of  $\geq 1$  D. The participants were evaluated for anisometropia while wearing their habitual correction (i.e. non-size lens) and reassessed 2-6 weeks later. All subjects were tested twice, and the total time for both visits was approximately two hours. All participants were recruited between February through June, 2016.

To be considered for this study, participants must have met all the inclusion criteria. Participants had to be 18 years of age or older, they had to have anisometropic spherical equivalent of  $\geq 1$  D, and regardless of the cause of the anisometropia. They had to have visual acuity of 20/25 or greater corrected vision.

The following is a description of the procedures that took place during the two visits that the 12 participants underwent. In the first visit, participants were interviewed about the medical and ocular history. Next, the participants had their ocular refraction measured, with an A-scan ultrasound biometry with topical anesthetic eye drops (0.5 % proparacaine), and a keratometry measurement. In addition to the preliminary interview and measurements, the participants completed a series of test to assess their stereopsis, their level of anisometropia, as well as their

visual acuity of their corrective vision. The participants' stereopsis was measured by the Random Dot E Test. Figure 2 showed all the materials used in the previous steps. The aniseikonia was measured by the Brecher Test (Appendix A) as well as, by use of the Aniseikonia Inspector Software test (Appendix B). The last task of the first visit was a questionnaire to measure the presence or severity of the symptoms commonly experienced by patients with aniseikonia impairment. The scale for the questionnaire was from 0-10: zero indicated the participant did not experience the symptom, and ten indicated that the symptom was experienced with the most severity (Appendix C).



**Figure 2:** Examination materials used in the study

Size lens spectacles were prescribed according to the findings of the first visits with new frames provided by the researcher. The researcher used two base curves. The first base curve was 2 D (the flattest base curve was used for most plus or least minus) and the second base curve was 6 D (steepest base curve used for most minus, or least plus). These spectacles lenses were the most readily available, and came premade (“stock”) by the manufacturing optician, and were prepared for edging and framing. It is important to emphasize that lenses changed the optical magnification properties of the spectacle lenses without affecting the original prescription. All lenses were edged at Pacific University Optical Dispensing Lab in Forest Grove, Oregon, by the researcher with new glasses frames. Size lens spectacles were given to the subjects to be used full time; participants could wear their contact lenses for one hour per day for any sport activity. All subject had a follow up visit after 2-6 weeks.

The second visit was a way to assess the efficacy of the size lenses that were issued after the first visit. After the participants had worn their size lenses for 2-6 weeks the same test carried out in the first visit were re-administered. The participants were asked to describe their experiences with the spectacles and underwent a visual acuity test, as well as a stereopsis measurement via the Random Dot E Test. Participants were assessed for horizontal aniseikonia via the Brecher Test and the Aniseikonia Inspector software test and their phoria compensated using the loose prism if needed. Lastly, participants were asked to reevaluate their symptoms and severity via the symptom questionnaire. After both visits, participants were allowed to keep their spectacles with size lenses.

### *Statistical Analysis*

For descriptive demographic characteristics of the study sample and calculated change in size per diopter of base curve change, Brecher and AIS; means, median, mode, range and standard deviations (SD) were used. For comparison of anisometropia and aniseikonia values between the three lenses (habitual spectacle, size lens spectacle (without prism) and size lens spectacle with prism), one-way analysis of variance (ANOVA) and the Tukey honest significant differences test for global comparisons among means were used. Differences were considered statistically significant for an  $\alpha$  value of 0.05 ( $p = 0.05$ ). Data correlations were determined using linear regression analysis and the Pearson product moment correlation coefficient was calculated. For comparison aniseikonia mean of habitual spectacle and size lens spectacle with Brecher test and AIS test, t-test significant differences test for global comparisons among means was used. For comparing symptoms, one-way ANOVA, each of the all individual symptom scores was compared between the three lenses (habitual spectacle, size lens spectacle without prism and size lens spectacle with prism).



## RESULTS

Thirteen patients met the inclusion criteria and were enrolled in the study. Three patients were excluded from the analysis because of incomplete follow-up. Ten subjects (all females), aged 23 to 48 years, completed the study. For their habitual optical correction, 8 patients used glasses, 1 patient used contact lenses and 1 used progressive glasses. Table X showed the demographic characteristics of the sample.

**Table 1:** Demographic characteristics of the study population

| Variable             | N  | Mean $\pm$ SD    | Range          |
|----------------------|----|------------------|----------------|
| Age                  | 10 | 29.60 $\pm$ 7.69 | 23.00 to 48.00 |
| Sphere               | 10 | 2.15 $\pm$ 4.16  | -8.88 to 3.25  |
| Cylinder             | 10 | 0.89 $\pm$ 0.87  | 2.50 to 0.00   |
| AL                   | 10 | 24.00 $\pm$ 1.62 | 21.34 to 26.17 |
| K_reading            | 10 | 44.13 $\pm$ 1.42 | 41.50 to 46.38 |
| Spherical Equivalent | 10 | 3.03 $\pm$ 4.12  | -10.13 to 2.63 |
| Anisometropia        | 10 | 1.96 $\pm$ 0.76  | 0.75 to 3.00   |

N= sample size, SD = standard deviation

AL = axial length differences between two eyes,

K\_reading = keratometry reading differences between two eyes

### *Medical History and Size Lens Spectacle Experience*

All subjects had no known medical history. Sixty percent of the subjects reported some discomfort using the size lens spectacles on the first day. Eighty percent of the population felt they are comfortable more with the size lens spectacle than their habitual spectacle especially for headache and reading difficulty on the following days. The remaining subjects did not feel any

difference between the two spectacles. Seventy percent of the subjects complained of photophobia with the size lens spectacles.

### *Refractive Error Types and Anisometropia*

**Table 2:** Anisometropia type and frequency

| <b>Anisometropia Type</b> | <b>Frequency</b> | <b>Percent</b> |
|---------------------------|------------------|----------------|
| Axial                     | 7                | 70.0           |
| Mixed                     | 3                | 30.0           |
| Refractive                | 0                | 0.0            |
| Total                     | 10               | 100.0          |

As shown on Table 2, the most frequent anisometropia type of the study population was axial (7 subjects) followed by the mixed type (3 subjects). Four of the subjects were hyperopic while the other six subjects were myopic. Six participants had a refractive error combined with astigmatism.

### *Visual Acuity and Stereopsis*

**Table 3:** Comparison of visual acuity and stereopsis in visit 1 and 2

| <b>Variable</b>                  | <b>N</b> | <b>Mean</b> | <b>SD</b> | <b>t</b> | <b>df</b> | <b>P</b> |
|----------------------------------|----------|-------------|-----------|----------|-----------|----------|
| Visual Acuity<br>Habitual spec.  | 10       | 0.78        | 0.17      | 5.09     | 9         | 0.000    |
| Visual Acuity<br>Size lens spec. | 10       | 0.99        | 0.15      |          |           |          |
| Stereopsis<br>Habitual spec.     | 10       | 52.05       | 58.92     | 1.00     | 9         | 0.343    |
| Stereopsis Size<br>lens spec.    | 10       | 51.30       | 59.42     |          |           |          |

Best-corrected visual acuity before used size lens spectacle averaged 20/28 in each eye (range, 20/40 to 20/20) and 20/20 in each eye (range, 20/25 to 20/15) after used size lens spectacle.

Table 3 presents the findings of a paired sample t-test to visual acuity, that found statistically significant differences between the habitual spectacle and size lens spectacle ( $P=0.00 < 0.05$ ,  $t=5.099$ ,  $df=9$ ), as (mean  $\pm$  SD) habitual spectacle ( $0.78 \pm 0.17$ ), while ( $0.9975 \pm 0.15$ ) to size lens spectacle. Also show the stereopsis in the visit 1 ranged from 12.50 to 160.00 sec of arc (mean [ $\pm$  SD],  $52.05 [\pm 58.93]$ ), wherever stereopsis in visit 2 ranged from 12.50 to 160.00 sec of arc (mean [ $\pm$  SD],  $51.30 [\pm 59.42]$ ). The findings of a paired samples t-test, that found no statistically significant differences in the stereopsis ( $P=0.343 > 0.05$ ,  $t=1$ ,  $df=9$ ) as mean stereopsis on visit 1 was 52.05 while mean stereopsis on visit 2 was 51.30. We found stereopsis reduced in visit 2, but there is enough evidence to conclude that there is not a difference in the mean stereopsis of the two visits.

### *Axial Length and Anisometropia*

**Table 4:** Prediction of anisometropia spherical equivalent by eye axial length

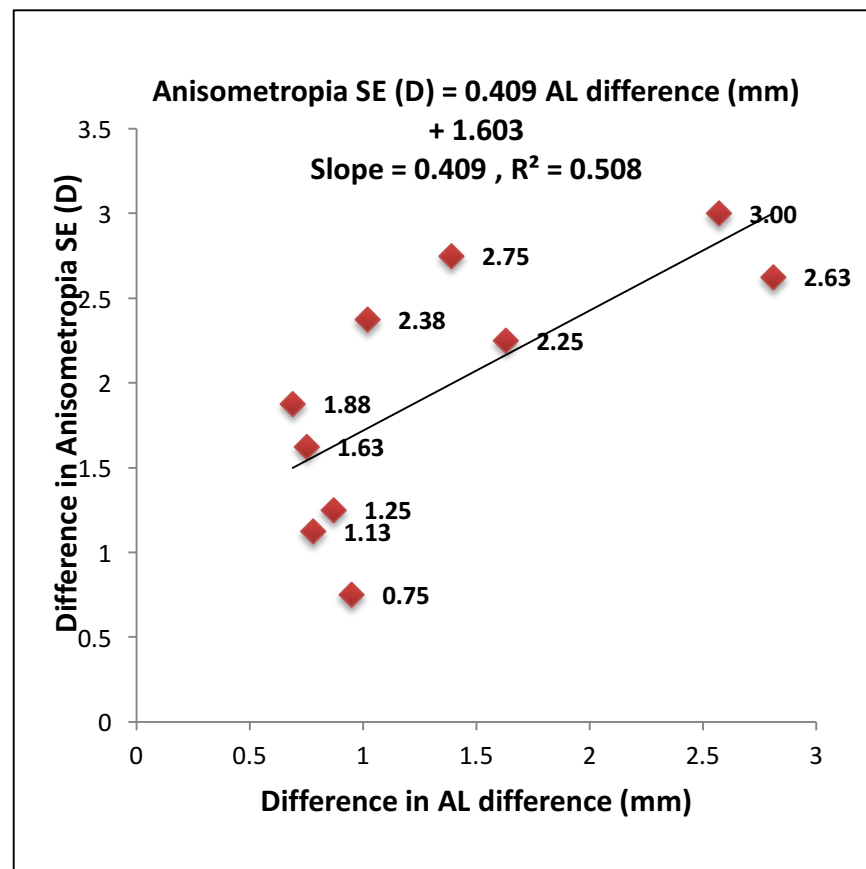
| Model          | Unstandardized Coefficients |            | R     | R <sup>2</sup> | t     | Sig.  |
|----------------|-----------------------------|------------|-------|----------------|-------|-------|
|                | B                           | Std. Error |       |                |       |       |
| (Constant)     | 1.603                       | 0.218      | 0.713 | 0.508          | 7.353 | 0.000 |
| AL_difference* | 0.409                       | 0.142      |       |                | 2.875 | 0.021 |

\* AL\_difference = axial length differences between two eyes

Table 4 presents the findings of prediction of anisometropia spherical equivalent (SE) differences between two eyes by axial length differences, that found  $R = 0.713$ , and  $R^2 = 0.508$ , the equation to predict the axial length and spherical equivalent relationship was:

$$\text{Anisometropia SE difference between two eyes} = 0.409 * \text{AL\_difference (mm)} + 1.603$$

This result shows a good model of predication about the relationship between the axial length and anisometric SE difference between the two eyes (Fig. 3)



**Figure 3:** Prediction of anisometropia spherical equivalent by axial length

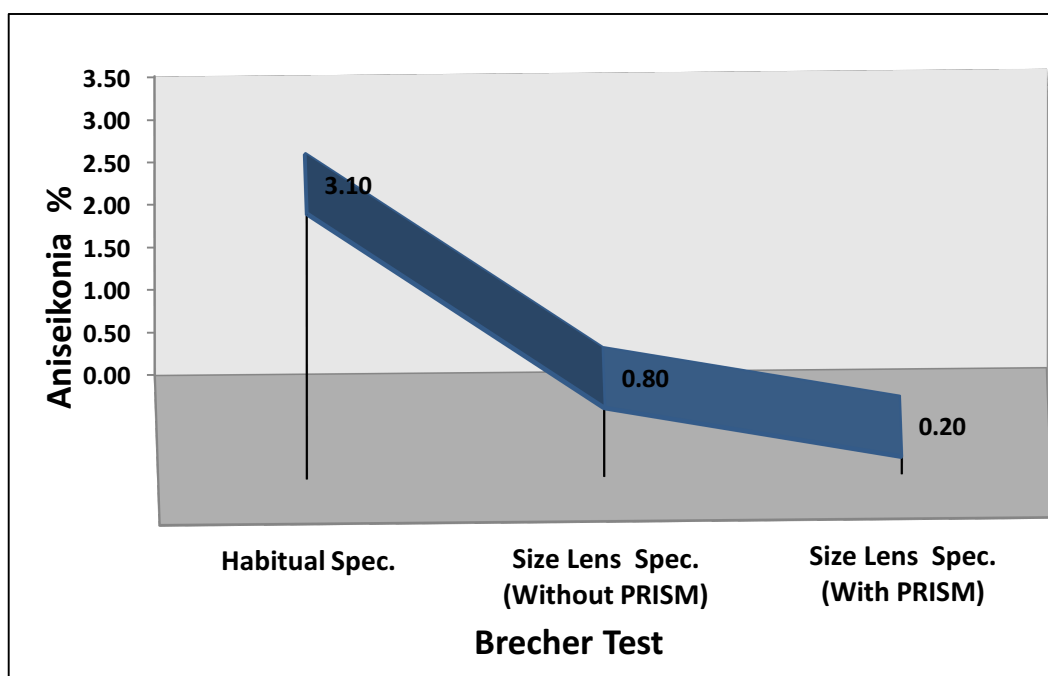
### *Aniseikonia test*

#### **a. Brecher test**

**Table 5:** Comparison of aniseikonia mean of habitual spectacle and size lens spectacle with Brecher test

| Variable                           | N  | Mean $\pm$ SD   | t     | df | P     |
|------------------------------------|----|-----------------|-------|----|-------|
| Habitual spec.                     | 10 | 3.10 $\pm$ 0.76 | 6.273 | 9  | 0.000 |
| Size lens spec.<br>(without PRISM) | 10 | 0.8 $\pm$ 1.22  |       |    |       |
| Habitual spec.                     | 10 | 3.10 $\pm$ 0.76 | 8.333 | 9  | 0.000 |
| Size lens spec.<br>(with PRISM)    | 10 | 0.20 $\pm$ 0.42 |       |    |       |

Table 5 presents the findings of a paired samples t-test to Aniseikonia test with Brecher, that found statistically significant differences between the Bercher habitual spectacle and Bercher size lens spectacle without prism ( $P= 0.00 < 0.05$ ,  $t=6.273$ ,  $df=9$ ) as mean Bercher was 0.80% without prism, while mean Bercher to habitual spectacle was 3.10 %, and illustrated that mean Bercher in size lens spectacle without prism was 0.80 % greater than mean Bercher in size lens spectacle with prism was 0.20, that means aniseikonia test is a lot better with Bercher size lens spectacle with prism (Fig. 4).



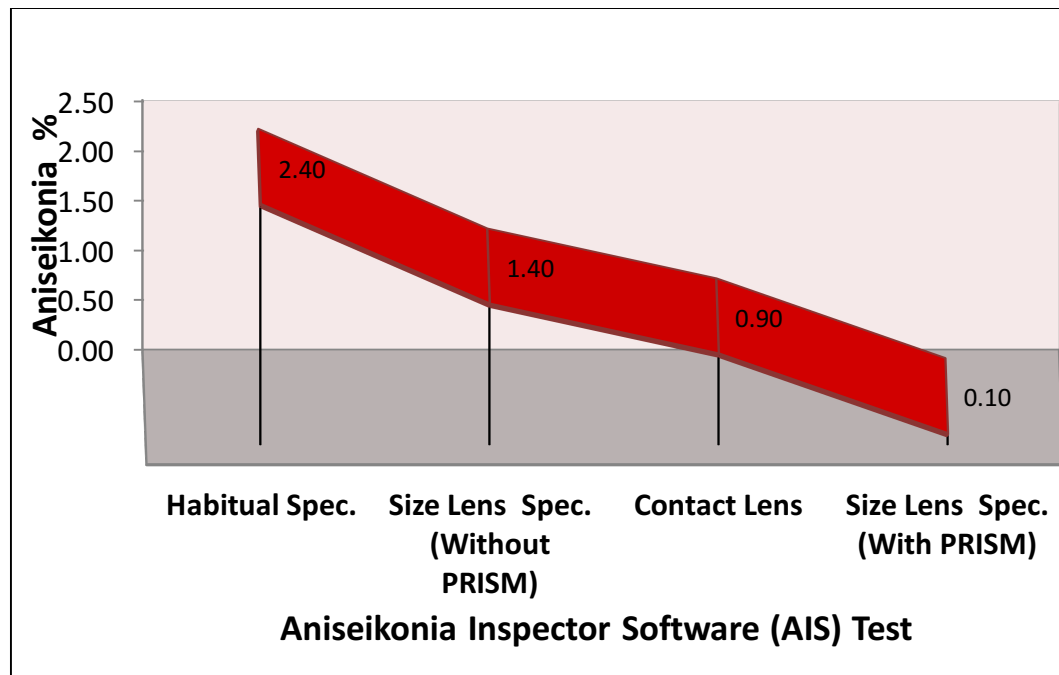
**Figure 4:** Aniseikonia mean of different spectacles with Brecher test

#### b. Aniseikonia Inspector Software (AIS)

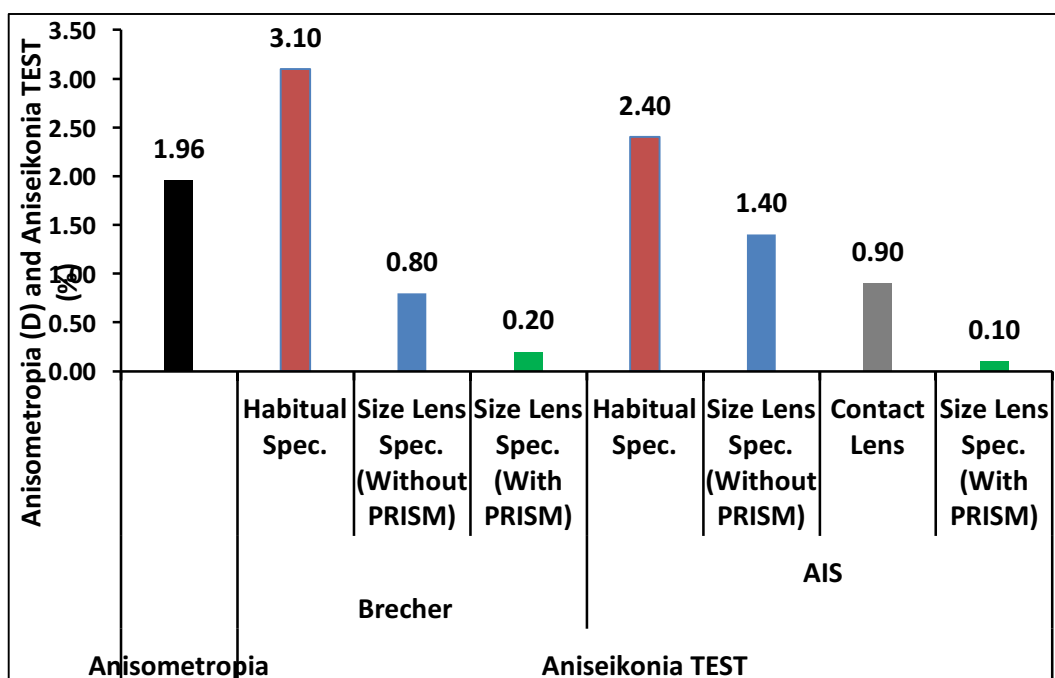
**Table 6:** Comparison of aniseikonia percentage of habitual spectacle to size lens spectacles with Aniseikonia Inspector Software (AIS)

| Variable                           | Mean $\pm$ SD   | t     | df | P     |
|------------------------------------|-----------------|-------|----|-------|
| Habitual spec.                     | 2.40 $\pm$ 2.17 |       |    |       |
| Size lens spec.<br>(without PRISM) | 1.40 $\pm$ 1.17 | 1.627 | 9  | 0.138 |
| Contact lens                       | 0.90 $\pm$ 1.52 | 2.09  | 9  | 0.067 |
| Size lens spec.<br>(with PRISM)    | 0.10 $\pm$ 0.32 | 3.29  | 9  | 0.009 |

Table 6 presents the findings of a paired sample t-test to aniseikonia test with Aniseikonia Inspector Software (AIS), that found statistically significant differences between the AIS habitual spectacle and AIS size lens spectacle with prism ( $P= 0.00 < 0.05$ ,  $t=3.29$ ,  $df=9$ ) as mean AIS size lens spectacle= 0.10 with prism, while mean AIS to habitual spectacle = 2.40, and illustrated that mean AIS in size lens spectacle without prism =1.40 greater than mean AIS in size lens spectacle with prism = 0.10, that means aniseikonia test is better a lot with AIS size lens spectacle with prism shown in Figure 5.



**Figure 5:** Aniseikonia mean of different lenses with AIS test



**Figure 6:** Means of anisometropia and aniseikonia of different correction with Brecher and AIS tests

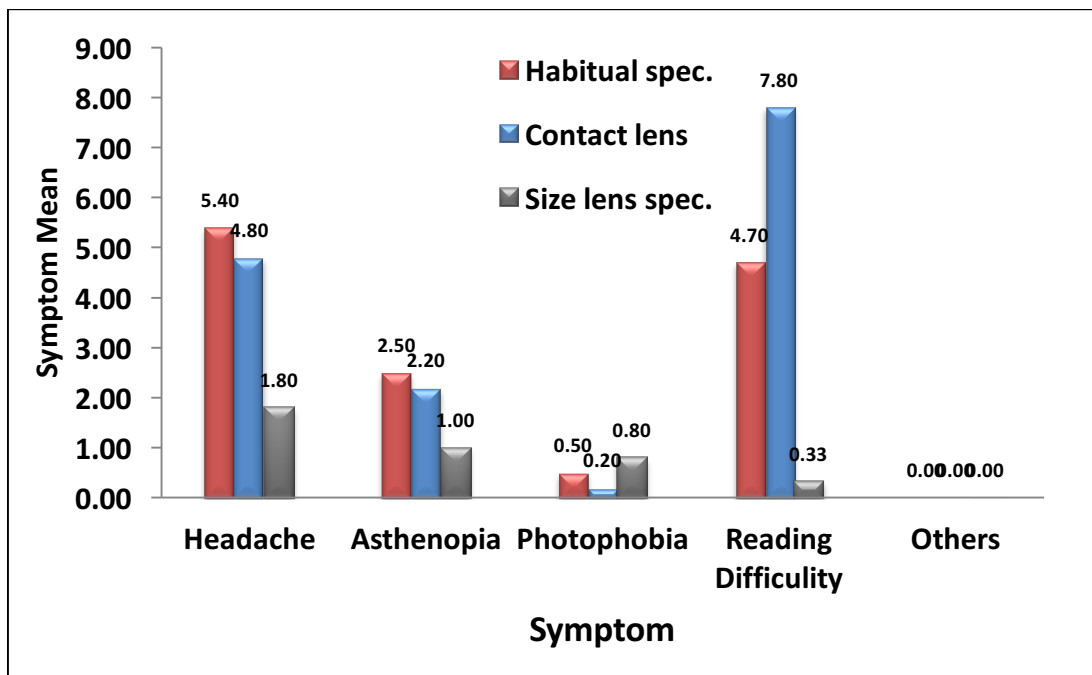
### Symptoms

**Table 7:** Comparison of symptom scores at each visit (habitual spectacle, contact lens

| Symptoms           | Habitual Spectacle | Contact Lens     | Size lens spectacle | F     | P     |
|--------------------|--------------------|------------------|---------------------|-------|-------|
|                    | Mean $\pm$ SD      | Mean $\pm$ SD    | Mean $\pm$ SD       |       |       |
| Headache           | 5.40 $\pm$ 7.152   | 4.80 $\pm$ 7.330 | 1.80 $\pm$ 3.676    | 0.943 | 0.402 |
| Asthenopia         | 2.50 $\pm$ 1058    | 2.20 $\pm$ 1.99  | 1.00 $\pm$ 1.41     | 2.235 | 0.126 |
| Photophobia        | 0.50 $\pm$ 0.71    | 0.20 $\pm$ 0.42  | 0.80 $\pm$ 1.48     | 0.946 | 0.401 |
| Reading Difficulty | 4.70 $\pm$ 10.39   | 7.80 $\pm$ 13.89 | 0.33 $\pm$ 0.71     | 2.988 | 0.067 |
| Others             | 0                  | 0                | 0                   | -     | -     |



Table 7 presents the findings of symptom scores at each study habitual spectacle, contact lens and size lens spectacle), that there were no statistically significant differences between (habitual spectacle, contact lens and size lens spectacle) of each symptom: headache ( $F(2,27)=0.943$ ,  $p=0.402>0.05$ ), asthenopia ( $F(2,27)=2.235$ ,  $p=0.126>0.05$ ), photophobia ( $F(2,27)=0.946$ ,  $p=0.401>0.05$ ), reading difficulty ( $F(2,27)=2.988$ ,  $p=0.067>0.05$ ), Others (no variance), so there is enough evidence to conclude that there is no difference in the mean of all symptom to three measurement (habitual spectacle, contact lens and size lens spectacle). Clinically, the mean of subjects symptoms score shows significant improvement with size lens spectacle for headache, asthenopia and reading difficulty (Fig. 7).



**Figure 7:** Subject symptoms with each type of lens

*Base curve change and Aniseikonia % change*

**Table 8:** Aniseikonia percentage change per base curve diopter

|                  | <b>BC change</b> | <b>Brecher</b> | <b>AIS</b>  | <b>Change in size per diopter</b> |              |
|------------------|------------------|----------------|-------------|-----------------------------------|--------------|
|                  | <b>D</b>         | <b>%</b>       | <b>%</b>    | <b>Brecher %</b>                  | <b>AIS %</b> |
| <b>N</b>         | 10               | 10             | 10          | 10                                | 10           |
| <b>Mean ± SD</b> | 1.65 ± 1.87      | 2.80 ± 1.14    | 2.10 ± 1.79 | 0.878 ± 0.66                      | 0.691 ± 0.79 |
| <b>Median</b>    | 0.75             | 3              | 1.5         | 0.75                              | 0.39         |
| <b>Mode</b>      | 0                | 3              | 1           | 0.75                              | 0.25         |

BC change = spectacle base curve difference between habitual spectacle and size lens spectacle

AIS = aniseikonia inspector software

Table 8 presents the findings of base curve change per diopter change in size, that found Mean ± SD to diopter change in size for Brecher (0.878 ± 0.66), and (0.691 ± 0.79) to diopter change in size for Aniseikonia Inspector Software (AIS). So every 1.00 D in spectacle base curve change will correct around 0.785 % (mean average of Brecher and AIS tests)

## DISCUSSION

Primarily, our study aims to provide better understanding of aniseikonia and how to treat it clinically with different methods (e.g. contact lenses). Aniseikonia can occur either as a difference in axial length or corneal power or both, as shown by our results.

Based on the finding observed on the first visit, we found that anisometropia spherical equivalent of  $\geq 1$  D cause aniseikonia of at least 1%. Also, anisometropia spherical equivalent resulted from the difference in axial length between the two eyes regardless the refractive error or anisometropia type according to the prediction equation (Fig. 3). This challenges the clinical rule of thumb that for every one millimeter of axial length difference between the two eyes results in 3 D of anisometropia.

Based on the result of the second visit, visual acuity improved one line with size lens spectacles. Stereopsis was not affected for all subjects except one who showed improvement from 20 to 12.5 sec of arc. We attribute this finding to the improvement of the image quality but we still do not know the exact effect of the size lens spectacles on stereopsis.

Our results showed that the size lens spectacles improved the aniseikonia, but the improvement is limited with most subjects by the Brecher and Aniseikonia Inspector software (AIS) tests. We discovered after the first two subjects that when we compensate the subjective phoria, all subjects except one reached zero percentage with both aniseikonia tests. After the third participant, we neutralized any subjective phoria by loose prism, as needed. We discovered that there was significant improvement of both aniseikonia tests with the prism. Aniseikonia measurement with size lens spectacles was easier to neutralize with the Brecher test than AIS, that could be because the AIS is more precise than Brecher. This result gives us a suggestion

clinically to measure the anisometropic patient's phoria before prescribing any size lens spectacles. Yet we cannot explain the optics by which the image sizes were corrected, except perhaps by using the SILO (Smaller In, Larger Out) effect. That is, base in prism magnifies the binocular image, and base out minifies it. We were unsuccessful in finding a relationship between refractive error and the corrective prism base direction, but no clear pattern emerged. For example, hyperopes in this study (n=4) did not routinely accept minifying BO prism, despite binocular spherical lens magnification. Similarly, myopes (n=6) in this study did not accept magnifying (BI) prism despite binocular lens minification.

There were no statistically significant difference of the symptoms between habitual spectacles, contact lenses and size lens spectacles, but there is a clinically-significant improvement of headache, asthenopia and reading difficulty with size lens spectacles compared to habitual spectacles and contact lenses. This is most probably due to the correction of the cortical image size. Comparing size lens spectacles to habitual spectacles, rates of headache decreased by 66.7 % and severity improved from severe to mild on the symptom scale (Fig. X). Incidence of asthenopia decreased by 60% and its severity improved as well. Surprisingly, severe reading difficulty decreased by 93%, and some patients had almost no difficulty (mean = 0.33). However, reading difficulty increased by 40% for contact lenses compared to habitual spectacles. We think that a possible explanation for the improvement of the headache, asthenopia and reading difficulty was that we neutralized the image size between the two eyes, which diminished binocular vision interference, by improving anisokonia and vision quality.

On the other hand, photophobia rates increased by 60 % with size lens spectacles compared to habitual spectacles, which are expected due to the fact that no antireflective

coatings were used for these lenses. More studies are required to compare the aniseikonia amount when treated by size lens spectacles and prism.

|             |      |          |        |             |       |
|-------------|------|----------|--------|-------------|-------|
| 0           | 1-2  | 3-4      | 5-6    | 7-8         | 9-10  |
| No symptoms | Mild | Moderate | Severe | Very severe | Worst |

**Figure 8: Subject Symptoms Scale**

In order to minimize each subject's aniseikonia, we compare the subject's habitual spectacle base curve to size lens spectacle base curve difference (4 D) and the aniseikonia amount (Appendix D). We found that the mean average of the two aniseikonia tests is 0.7845 % per one diopter of anisometropia spherical equivalent. We do not think that we can generalize this as a clinical rule due to the small sample size, but future studies may need to establish a more precise rule-of-thumb than the traditional 1D of anisometropia equaling 1% aniseikonia. Subjects who used plastic frames were more comfortable than subjects who use metal frames regardless of their type of refractive error. It might be that the subjects using the metal frames suffer from awareness of the lens edge thickness more than who used the thicker plastic frames. This was indicated by one subject who had a better visual experience when her frame was changed from metal to plastic.

There are a few limitations to our study. First, the sample size was small. Second, we do not know the relation between the improvement of aniseikonia and the prism effect.

## **CONCLUSION**

Size lens spectacles are a good option for patients who have axial or mixed anisometropia. Every 1.00 D change in the base curve of spectacle lenses between right and left lenses will correct approximately 1 % of the aniseikonia. Center thickness and refractive index also are important factors need to be examined in relation to base curve change in spectacles between right and left lens for different refractive errors. Further studies are necessary to show the effect of prism on aniseikonia.

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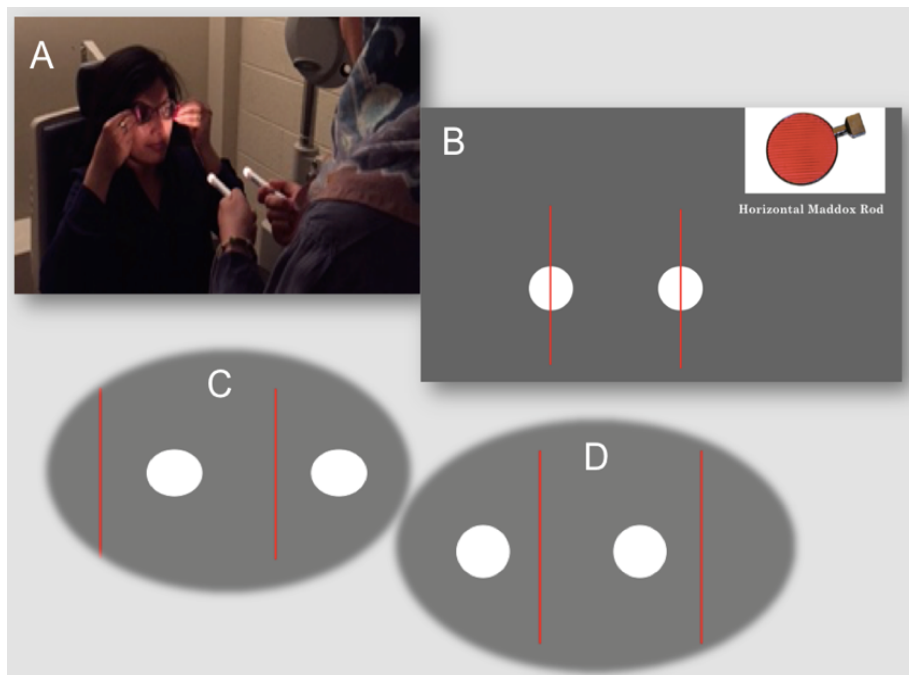
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## APPENDIX

### A. Brecher Test<sup>43</sup>

This test is named after Dr. Brecher after he originally described the procedure in 1951. The test itself is rather simple. Two penlights, a Maddox rod, and a few hand-held focal magnifiers, or size lenses, are the only materials needed. The examiner holds the penlights a set distance apart and points them at the participant; while the participant holds the Maddox rod over their right eye with the axis at 180 degrees (Fig. 9, A).

The examiner instructs the participant to determine the location of the two red lines in relation to the penlights. If the red line bisects a penlight, then this is considered zero-percent aniseikonia (Fig. 9, B). The participant has heterophoria if both red lines seen are shifted to one side; this can be compensated for using loose prism (Fig. 9, C and D). However, if the red lines do not coincide with the distance between the penlights, then the iseikonic lens is shifted over the opposite eye, this allows for a quantifiable result in percentage form. If the process is repeated with the Maddox rod at an axis of 90 degrees, the examiner can quantify vertical aniseikonia. It has been reported to be as accurate as 0.5%.<sup>44</sup> This procedure can also be done with the Maddox rod at axis 90 degrees in order to quantify vertical aniseikonia.



**Figure 9: Bercher Test**

### **B. Aniseikonia Inspector Software test<sup>45</sup>**

The following is a description of the Aniseikonia Inspector Software used to measure participants' horizontal aniseikonia. The Aniseikonia Inspector is a direct-comparison eikonometry test. Participants wear anaglyphic glasses (green-red lenses) and are then asked to assess if two rectangular boxes are of equal size. The word eikonometry refers to the measurement of aniseikonia by displaying different sized images to each eye while wearing anaglyphic glasses and presentations.

During both visits, computerized software will be used to measure the retinal image size differences, or the level of aniseikonia in each participant. To carry out the test, participants are positioned in front of a monitor at a distance of approximately 40 cm wearing the anaglyphic glasses. To calibrate the test, participants must align a straight vertical and horizontal line. The

calibration was a control for fixation disparity. Participants are asked to look through anaglyphic filters that are placed over their respective spectacles, and look directly at a target on the monitor in front of them. For each comparison, they choose the largest test target by pressing the corresponding arrow key, or 'E' if the images are equal (Fig. 10).

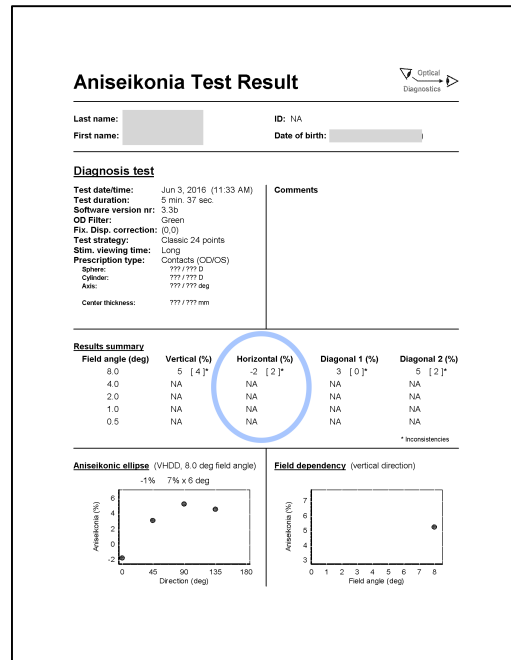


**Figure 10:** A subject performing the Aniseikonia Inspector Software test

The result is given as a positive or negative percentage; the positivity or negativity of the measure is in reference to the right eye (Fig. 11). The software instructions state: “The more inconsistent responses the patient makes, the less accurate the aniseikonia value may be. As a rough guide an inconsistency value of 3, 4, or more should trigger you to look at the raw data, possibly re-instructing the patient and repeating the test.”


For more information, see the website:

<http://opticaldiagnostics.com/products/ai/index.html>



**Figure 11:** Aniseikonia Test result sheet “Horizontal [%]” column used in this study”

## C. Examination Form



**Treating Aniseikonia with Stock Base Curve Manipulation in Asymptomatic Adults**

**Examination Form**

Subject ID: \_\_\_\_\_

Date of Birth: \_\_\_\_\_ Today's Date: \_\_\_\_\_

Sex: ☐ Male ☐ Female

---

**1. Medical History**

|   | Yes | No | If yes, please specify |
|---|-----|----|------------------------|
| • Do you currently have any health problems?          |     |    |                        |
| • Do you currently have any eye problems or diseases? |     |    |                        |
| • Do you have any eye injury / surgery?               |     |    |                        |
| • Are you allergic to any medications or eye drops?   |     |    |                        |
| • Do you wear eyeglasses or contact lenses?           |     |    |                        |
| • Do you have any chief complaint today?              |     |    |                        |
| • Others  |     |    |                        |

**2. Lenses types**

☐ Non-Aniseikonic Lenses ☐ Aniseikonic Lenses

How many hours per day you wear the lenses? \_\_\_\_\_ hours/day

If NOT, why \_\_\_\_\_

**3. Visual acuity:**

|                                 | OD   | OS   | OU   |
|---------------------------------|------|------|------|
| Without Rx                      | 20 / | 20 / | 20 / |
| With Rx (habitual/ Aniseikonia) | 20 / | 20 / | 20 / |

• Present Rx: \_\_\_\_\_ Base Curve: \_\_\_\_\_

OD: \_\_\_\_\_ OS: \_\_\_\_\_ Base Curve: \_\_\_\_\_

**4. Subject Eye Measurements:**

|                     | OD      | OS      |
|---------------------|---------|---------|
| Axial length        | mm      | mm      |
| Keratometry reading | D       | D       |
| Stereopsis          | sec arc | sec arc |
| Aniseikonia amount  | %       | %       |

**5. Subject Symptoms Scale:**

| 0           | 1-2  | 3-4      | 5-6    | 7-8         | 9-10  |
|-------------|------|----------|--------|-------------|-------|
| No symptoms | Mild | Moderate | Severe | Very severe | Worst |

Headaches 0 1 2 3 4 5 6 7 8 9 10

Anisometropia (fatigue, burning, tearing, ache, pain, etc.) 0 1 2 3 4 5 6 7 8 9 10

Photophobia 0 1 2 3 4 5 6 7 8 9 10

Reading difficulty 0 1 2 3 4 5 6 7 8 9 10

Others: specify 0 1 2 3 4 5 6 7 8 9 10

Investigator name: \_\_\_\_\_

Signature: \_\_\_\_\_

1
2

**Figure 12:** Examination form used in the study

## D. Steps to Calculate the Base Curve (BC) and Aniseikonia Relationship:

1. Calculate the OD – OS BC in habitual spectacle. Keep sign convention + or -.
2. Calculate the OD – OS BC in size lens spectacle. Keep sign convention + or -.
3. Subtract #1 from #2. This is the net BC change
4. Calculate change in aniseikonia from Brecher or AIS software (pre – post)
5. Divide #4 by #3. Equal to aniseikonia amount per BC diopter

## **E. Glossary**

|           |                                  |
|-----------|----------------------------------|
| AL        | Axial length                     |
| ANOVA     | Analysis of variance             |
| D         | Diopter                          |
| df        | Degree of freedom                |
| 'E'       | Enter                            |
| F         | distribution variable            |
| IOL       | Intraocular lens                 |
| K_reading | keratometry reading              |
| N         | Sample size                      |
| OD        | Right eye                        |
| OS        | Left eye                         |
| P         | p-value                          |
| R         | Sample Correlation coefficient   |
| $R^2$     | Multiple correlation coefficient |
| ROP       | Retinopathy of prematurity       |
| SD        | Standard deviation               |
| SE        | Spherical equivalent             |
| Sig.      | Significance                     |
| Spec.     | Spectacle                        |
| t         | Student's t variable             |
| VER       | Visual evoked response           |

**Table 9:** Profile and clinical characteristic of subjects (1)

| Subject NO. | Age | Eye | Refraction          | SE     | Anisometropia | AL Dif. | K. Dif. | Anisometropia Type | Base Curve         | Base Curve          | VA                 | VA                  |
|-------------|-----|-----|---------------------|--------|---------------|---------|---------|--------------------|--------------------|---------------------|--------------------|---------------------|
|             | Y   |     |                     | D      | D             | mm      | D       |                    | D                  | D                   |                    |                     |
|             |     |     |                     |        |               |         |         |                    | Habitual spectacle | Size Lens spectacle | Habitual spectacle | Size Lens spectacle |
| 1           | 23  | OD  | - 3.25 – 1.00 X 35  | -3.75  | 0.75          | -0.95   | -0.25   | Axial              | 1                  | 2                   | 20/25              | 20/25 +3            |
|             |     | OS  | - 4.50 DS           | -4.5   |               |         |         |                    | 1                  | 6                   | 20/25              | 20/25 +2            |
| 2           | 28  | OD  | -5.75 – 1.00 X 05   | -6.25  | 1.625         | -0.75   | -0.62   | Mixed              | 2.5                | 2                   | 20/25 -2           | 20/20               |
|             |     | OS  | -6.75 – 0.75 X170   | -7.875 |               |         |         |                    | 2.5                | 6                   | 20/25 -2           | 20/20               |
| 3           | 29  | OD  | PI – 0.25 X 180     | -0.125 | 2.75          | -1.39   | -0.5    | Axial              | 1                  | 6                   | 20/25              | 20/20               |
|             |     | OS  | + 3.00 – 0.25 X 65  | -2.875 |               |         |         |                    | 1                  | 2                   | 20/30              | 20/25               |
| 4           | 26  | OD  | - 2.25 – 0.50 X175  | -2.5   | 2.375         | -1.02   | -0.12   | Axial              | 1.5                | 6                   | 20/40              | 20/15               |
|             |     | OS  | Plano               | -0.125 |               |         |         |                    | 1.5                | 2                   | 20/25              | 20/25               |
| 5           | 25  | OD  | + 1.5 -1.25 X170    | -0.875 | 1.125         | 0.78    | 0       | Axial              | 3                  | 6                   | 20/20              | 20/15 -1            |
|             |     | OS  | + 2.5 -1.00 X180    | 2      |               |         |         |                    | 2.5                | 2                   | 20/25              | 20/15 -2            |
| 6           | 29  | OD  | + 3.25 – 1.25 X 160 | 2.75   | 2.625         | -2.81   | -0.25   | Axial              | 5                  | 2                   | 20/40 +2           | 20/30 -2            |
|             |     | OS  | + 1.00 – 2.00 X 170 | -0.125 |               |         |         |                    | 2.5                | 6                   | 20/20              | 20/20               |
| 7           | 48  | OD  | - 6.50 – 1.75 X 176 | -7.375 | 1.25          | 0.87    | 0.5     | Mixed              | 2                  | 6                   | 20/30 -1           | 20/20               |
|             |     | OS  | - 5.25 – 1.75 X 05  | -6.125 |               |         |         |                    | 2.5                | 2                   | 20/30 -1           | 20/20               |
| 8           | 25  | OD  | -7.75 -2.5 X 178    | -9     | 2.25          | -1.63   | -0.25   | Axial              | 1                  | 2                   | 20/30 +2           | 20/20               |
|             |     | OS  | -10 -2.5 X 175      | -11.25 |               |         |         |                    | 1                  | 6                   | 20/25 -2           | 20/20               |
| 9           | 25  | OD  | - 2.00 – 0.25 X106  | -2.125 | 1.875         | 0.69    | 1       | Mixed              | 1                  | 2                   | 20/20              | 20/20 +2            |
|             |     | OS  | - 4.00              | -4     |               |         |         |                    | 1.5                | 6                   | 20/20              | 20/20 +2            |
| 10          | 38  | OD  | + 3.25              | 3.25   | 3             | -2.57   | -0.95   | Axial              | 2                  | 2                   | 20/25              | 20/20 +2            |
|             |     | OS  | + 0.25              | 0.25   |               |         |         |                    | 2                  | 6                   | 20/20              | 20/20 +2            |

OD = right eye, OS = left eye, SE = Spherical Equivalent, AL difference = AL difference between OD and OS, K. differences = keratometry reading difference between between OD and OS, VA = visual acuity



**Table 10:** Profile and clinical characteristic of subjects (2)

| Subject | Lens Type       | Stereopsis | Aniseikonia test % |               |       |          | Symptoms score |             |                    |        |
|---------|-----------------|------------|--------------------|---------------|-------|----------|----------------|-------------|--------------------|--------|
|         |                 | Rondot 3   | Brecher            | AIS           | prism | Headache | Asthenopia     | Photophobia | Reading Difficulty | Others |
|         |                 | “sec arc”  | Without Prism      | Without Prism |       |          |                |             |                    |        |
| 1       | Habitual spec.  | 20         | 3                  | 6             |       | 4        | 4              | 0           | 0                  | 0      |
|         | CL              | NA         | NA                 | 0             |       | 2        | 4              | 0           |                    | 0      |
|         | Size lens spec. | 12.5       | 0                  | 3*            | 10 BI | 0        | 0              | 4           | 0                  | 0      |
| 2       | Habitual spec   | 32         | 3                  | 0             |       | 3        | 3              | 1           | 4                  | 0      |
|         | CL              | NA         | NA                 | 0             |       | 2        | 3              | 1           | 4                  | 0      |
|         | Size lens       | 32         | 1                  | 0             | NA    | 0        | 2              | 3           | 0                  | 0      |
| 3       | Habitual spec   | 160        | 3                  | 1             |       | 2-3      | 4              | 0           | 3-4                | 0      |
|         | CL              | NA         | NA                 | 4             |       | 2-3      | 4              | 0           | 3-4                | 0      |
|         | Size lens spec. | 160        | 3*                 | 2*            | 5 BI  | 1        | 2              | 0           | 0                  | 0      |
| 4       | Habitual spec   | 16         | 2                  | 2             |       | 2        | 3              | 1           | 3                  | 0      |
|         | CL              | NA         | NA                 |               |       | 2        | 4              | 1           | 3                  | 0      |
|         | Size lens spec. | 16         | 1                  | 0             | NA    | 2        | 2              | 1           | 2                  | 0      |
| 5       | Habitual spec   | 32         | 2                  | 1             |       | 1-2      | 0              | 0           | 0                  | 0      |
|         | CL              | NA         | NA                 | NA            |       | 1-2      | 0              | 0           | 0                  | 0      |
|         | Size lens spec. | 32         | 0                  | 2*            | 4 BI  | 1-2      | 0              | 0           | 0                  | 0      |
| 6       | Habitual spec   | 63         | 4                  | 4             |       | 0        | 3              | 0           | 2                  | 0      |
|         | CL              | NA         | NA                 | 2             |       | 0        | 2-3            | 0           | 3                  | 0      |
|         | Size lens spec. | 63         | 0                  | 3*            | 2 BO  | 0        | 2-3            | 0           | 0                  | 0      |
| 7       | Habitual spec   | 12.5       | 3                  | 1             |       | 0        | 1              | 1           | 2                  | 0      |
|         | CL              | NA         | NA                 | 0             |       | NA       | NA             | NA          | NA                 | NA     |
|         | Size lens spec. | 12.5       | 0                  | 2*            | 3BI   | 0        | 0              | 0           | 1                  | 0      |
| 8       | Habitual spec   | 12.5       | 3                  | 2             |       | 0        | 0              | 2           | 0                  | 0      |
|         | CL              | NA         | NA                 | 0             |       | 0        | 3-4            | 0           | 0                  | 0      |
|         | Size lens spec. | 12.5       | 0                  | 1             | NA    | 0        | 0              | 0           | 0                  | 0      |
| 9       | Habitual spec   | 12.5       | 5                  | 2             |       | 5        | 4              | 0           | 0                  | 0      |
|         | CL              | NA         | NA                 | 2             |       | 5        | 5              | 0           | 0                  | 0      |
|         | Size lens spec. | 12.5       | 3*                 | 2*            | 4 BO  | 1        | 4              | 0           | 0                  | 0      |
| 10      | Habitual spec   | 160        | 3                  | 4             |       | 5        | 3              | 0           | 0                  | 0      |
|         | CL              | NA         | NA                 | 1             |       | 2        | 1              | 0           | 0                  | 0      |
|         | Size lens spec. | 160        | 0                  | 1*            | 2 BI  | 2        | 0              | 0           | 0                  | 0      |

Habitual spec.: Habitual spectacle, CL: contact lens, Size lens spec.:size lens spectacle, AIS : aniseikonia inspector software, NA: not available, BI: base in, BO:base out

\* aniseikonia improve to 0% when neutralize with prism with size lens spectacle

